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Deformation and ballistic performance of conical aluminum projectiles impacting thin aluminum targets: Influence of apex angle

Vijeesh Vijayan[a,*], S. Hegde[b], N.K. Gupta[b]

[a] *Robert Bosch Engineering and Business Solutions Private Limited, Bangalore 560103, India*
[b] *Department of Applied Mechanics, Indian Institute of Technology Delhi, New Delhi 110016, India*

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ABSTRACT

Mechanisms of projectile defeat and ballistic resistance of thin targets impacted by tip-deformable conical projectiles have been discussed in the context of the influence of apex angle of the projectile. Transition in target local failure modes occurred as the projectile apex angle was altered. The effect on projectile deformation and ballistic properties has also been discussed. A brief discussion on projectile deformation mechanism and projectile defeat near ballistic limit velocities with supporting experimental evidence is included. Numerical simulation using ABAQUS/Explicit has been able to effectively predict the projectile deformation and associated target behavior.

1. Introduction

Projectile impact experiments are of special interest as method to produce locally intense loads of different magnitudes. Most of the reported ballistic impact studies have considered either the target or the projectile to be rigid. Researches on impact of blunt or pointed projectiles with rigid armour plates have been employed for evaluating material properties at high strain rates or to evaluate deformation or fracture of projectiles [1–2]. On the other hand, several studies using rigid projectiles have been done for ballistic evaluation of targets [3–6]. An interesting regime of impact is where both the projectile and target undergo deformation. Published studies on projectile deformation and associated target behavior largely concentrate either on impact on thick or semi-infinite targets or on impacts at high or hyper velocity regimes [7–11] wherein the projectiles undergo prominent changes in shape and/or lose mass through erosion. In the case of thinner targets and impacts at low velocities involving ductile materials, experiments reveal only minimal deformation of the projectile and much of its kinetic energy is expended in inducing target damage. Small- scale deformation of blunt projectiles when impacting thin targets at subordnance velocities between 25 m/s and 500 m/s have been reported [12]. In their studies on the effect of target thickness, Borvik et al. [13] has accounted for blunt projectile deformation and associated deformation of thin targets. Projectile deformation in similar situations may cause unpredictable target responses [14–15]. It is necessary to establish the effect of parameters like nose shape, target thickness and impact velocity on the deformation characteristics of thin ductile targets impacted by deformable pointed projectiles, because of inadequate published data.

A series of experiments were conducted using conical aluminum projectiles to understand the effect of various target and projectile parameters on deformation, damage and ballistic behavior of aluminum projectile-target system. The scope of the current paper is however restricted to discussion of the effect of projectile apex angle on the deformation and ballistic behavior of aluminum projectiles during normal impact on aluminum targets of thickness 2.5 mm. Experimental evidence for occurrence of a brief dwell phase has been presented. Dependence of ballistic resistance of thin targets on the transition in the target local failure has been discussed. A discussion of projectile defeat by entrapment has also been included presenting experimental evidence. The results of the numerical simulations using finite elements carried out using ABAQUS/Explicit for specific cases are also included.

2. Experimental details

Low velocity normal impact experiments were conducted using cylindrico-conical projectiles with diameter of approximately 15.6 mm weighing 29.5 g made from Al 6063-T6 (Al0.7Mg0.4Si) rod stock, and 2.5 mm thick aluminum targets cut from strain hardened Al 1100 (Al0.12Cu1Si) sheets of different thickness. The velocity recorded ranged from approximately 70 to 130 m/s. The choice of the target thickness was governed by the observation of noticeable projectile tip deformation and occurrence of perforation within the range of impact velocities employed during the initial trials, while exhibiting global deflection.

* Corresponding author.
E-mail address: mailvijeeshvijayan@yahoo.com (V. Vijayan).

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Projectiles were launched from a compressed air operated smooth bore gun with a brass barrel and were allowed to be completely air borne prior to impact. An aluminum foil based velocity measurement system was used to measure the projectile velocity before and after impact. The measurement system consisted of aluminum foil sets, a dc power source and a digital storage oscilloscope forming a circuit. A schematic of the experimental setup including the velocity measurement instrumentation is shown in Fig. 1.

The projectiles that perforated the targets were carefully captured in a recovery box filled with cushioning materials. The detail of projectile geometry is shown in Fig. 2, and their dimensions are given in Table 1. The mechanical properties of the target used are given in Table 2. Sixteen holes of diameter approximately 7.94 mm were drilled at a pitch diameter of 230 mm in all the targets to match the arrangement of holes in the annular fixtures used to provide a circular span of 206 mm while fixing.

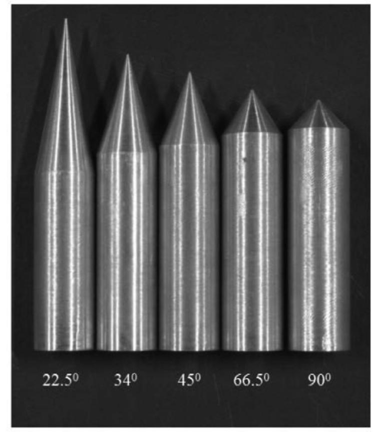

Fig. 2. Projectiles used in the current study before impact.

3. Projectile deformation

3.1. *Influence of apex angle*

The projectiles were found to undergo axial and lateral deformation at the tip. Projectiles with apex angles 22.5°, 34° and 45° underwent tip flattening, ejected a plug and further caused radial cracking and petalling in targets. The region around the tip transforms into an approximately frustum shaped volume with a very small included angle between the axis and the outer edge, with no significant barreling. Based on measurement, the height of the frustum shaped deformed region is approximately 0.75 to 1.75 times the tip diameter for various cases. This dimension is very difficult to be measured practically as a well defined transition between the deformed and undeformed portion of the conical nose cannot be easily identified. Geometrically calculated angle of the nose based on measurements is approximately 7.5° to 16° with respect to the vertical plane for apex angles 22.5° to 45°. Projectiles with apex angles 66.5° and 90° underwent tip-rounding. No plugs were recovered in these cases. The original luster of the projectile surface was lost during contact. There were marks of friction on the shank of the projectile at velocities close to the ballistic limit.

The deformed projectiles after impact can be seen in Fig. 3 and changes in their length and tip diameter with apex angle in Fig. 4(a) and (b). Accounting for the transition in projectile deformation behavior mentioned above, the reduction in length was assumed to vary exponentially with apex angle. Since the flattened tip diameter was not measurable precisely in case of projectiles with apex angles 66.5° and 90° these have not been included in Fig. 4(b). The tip-diameter measurement was approximate and the values approached those of the diameter of the plug at the impact side.

The variation of change in projectile length with impact velocity was evaluated for a particular case of tip-flattening projectile (apex angle 22.5°). The tip diameter was found to be approximately the same and the length of the shank remained same after impact at measured velocities. Nevertheless it is evident that the projectile deformation is dependent on the impact velocity at very low velocities, where valuable information regarding projectile velocity was lost because of experimental limitations. There definitely is a critical velocity beyond which the change in projectile length and the tip diameter seems to get stabilized in the tip-flattening cases as the impact velocity increases.

3.2. *A note on the deformation mechanism*

For a typical case of tip-flattening, it is observed that the pointed tip of projectiles causes negligible indentation at the location of initial contact as observed at the centre of the recovered plug (Fig. 5).

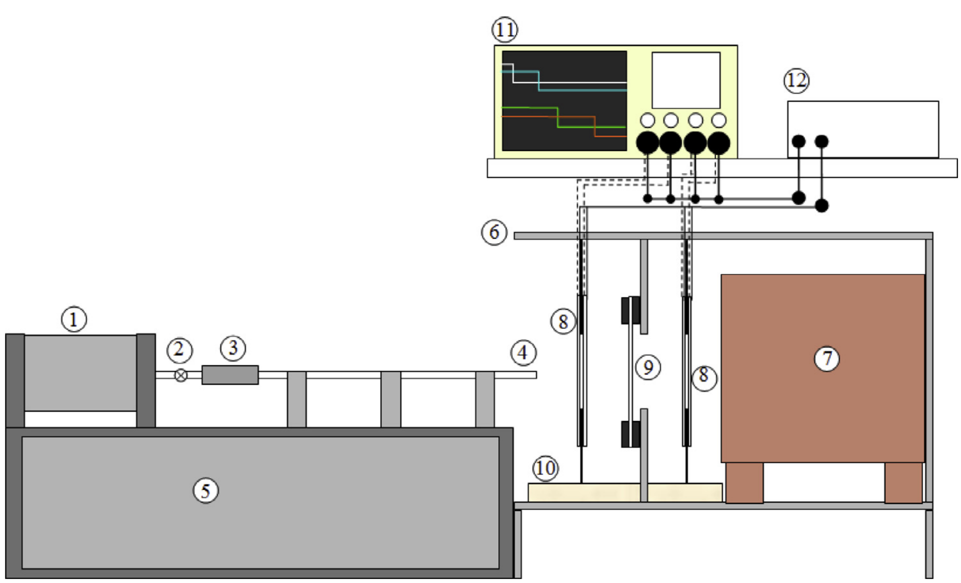

Fig. 1. Schematic representation of experimental setup ((1) Air cylinder, (2) Ball valve / Trigger, (3) Port for breech loading of projectile, (4) Barrel, (5) Machine tool bed, (6) Frame, (7) Projectile recovery box, (8) Foil set for velocity measurement, (9) Target, (10) Additional cushioning, (11) Oscilloscope, (12) Power supply and conditioning circuit).

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